Development of Miniature Modular Digital Altimeter

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Abstract—**Altimetry is defined as the method of measuring heights above sea level. Measuring height has been achieved by various methodologies in the past, ranging from U-shaped columns of mercury or water, sealed pressurized balloons of air or more modern approaches such as the Global Positioning System (GPS). However, all these methods are either quite bulky or power hungry and so a low cost, light weight unit would be useful for various applications. Shown here is a small microprocessor controlled system that utilizes an air pressure sensor that can be adjusted to the current air pressure, run off a 6 Volt source and the height displayed on a Liquid Crystal Display (LCD) screen. This allows it to be used as a standalone module or integrated into a much larger system. This includes applications such as robotics and Unmanned Aerial Vehicles (UAVs) to personal handheld units for use in leisure activities or by security or rescue personnel.**

Keywords – Altimeter; Air Pressure; Modular Design; Mircoprocessor; PIC18F

I. INTRODUCTION

The main hardware implications for interfacing a simple barometric pressure sensor with a microprocessor are errors described thusly [1 – 2]:

1. **Temperature drift error:** For which an algorithm has to be developed and incorporated into the microprocessor instructions.
2. **Compensated pressure:** This is filtered digitally to reach a median value, ultimately increasing accuracy of the end height.

Previous systems were able to deliver height information between 750 metres under the sea level and 10,000 metres above sea level, with acceptable precision. Major shortcomings with such systems are the effect of temperature fluctuations on the readings and as such, must be compensated for. Equation 1 shows an equation relating elevation to pressure and temperature.

$$'H = \frac{T_0}{\beta} \times \left[\left(\frac{p_H}{p_0}\right)^{-\frac{\beta R}{g}} - 1\right] + H_0 \qquad (1)$$

Where:
$R = 287.05287 \mathrm{m^2/(K \times s^2)}$ is the specific gas constant
$g = 9.80665 \mathrm{N/m^2}$ is the standard sea level acceleration due to gravity
$p_0 = 101.325$ kPa is the standard atmospheric static pressure at sea level
$T_0 = 288.15$ K is the standard atmospheric temperature at sea level
$\beta = -6.50$ K/km is the vertical temperature change rate within the range of 0 to 11km.
$H_0 = 0$m is the sea level

As height is dependant both on pressure and temperature parameters, the readings output by the sensor are prone to approximation errors when any one of the terms involved are approximated to a standard value. Owing to this, the system developed in [1] introduces the use of sensor calibration, temperature compensation, and a combination of hardware and software filtering. Software-wise, the operation is outlined in Figure 1. The digital signal processing methods, in effect a corrective measure, help to deliver much higher accuracy readings, without the use of any additional information provided by other sensors or systems (aiding in the low cost and compact approach).

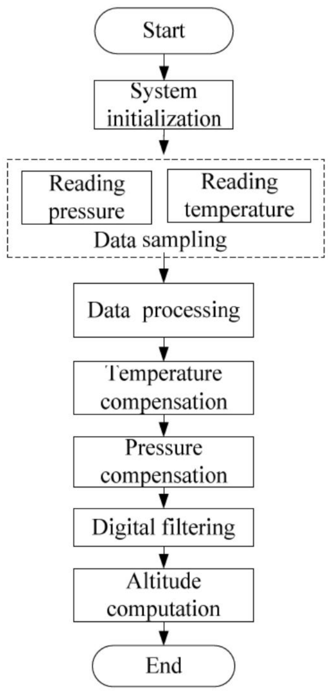

Figure 1 – Software system outlined in the Micro Aerial Vehicle (MAV) described in [1]

The relationship between atmospheric pressure, elevations between 0 and 11 km, and temperature is shown in Figure 2.

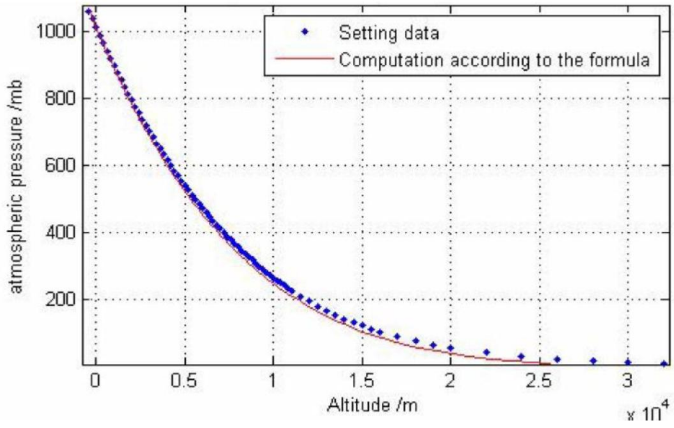

Figure 2 – Relationship between atmospheric pressure and altitude [1]

II. DESIGN OF SYSTEM

This system utilises the MPL115A1 barometric pressure sensor [3]. Its compact dimension and small current draw make it suitable for low-power applications and being capable of providing accurate pressure readings from 50 kPa to 115 kPa, with reference to vacuum (0 Pa).

Given that both the compensated pressure and temperature factor in the algorithm, the sensor is able to deliver an absolute value of pressure and consequently, a very good altitude approximation. Moreover, it does not require calibration when used in environments which are similar in terms of average temperature. According to [4], a measureable barometric pressure range of 50 – 115 kPa gives a range of measureable altitudes above sea level of 0 meters to approximately 7628 meters, as shown previously in Figure 2. When used in highly dissimilar geographical areas, the system requires adjustment of the sea level pressure and temperature parameters. As possible further development, a calibration system to adjust the altitude equation parameters to the appropriate local values, along with a signal filtering system could be incorporated. A digital signal processor would enable the computation of an accurate mean value of altitude by reducing or eliminating errors induced by the temperature drift or compensated pressure parameters, even in the absence of additional information.

The practical circuit built for the system prototype is shown in Figure 3. The system consists of a PIC18F microcontroller connected to the breakout board containing the MPL115A1 sensor to read in the air pressure and temperature, and an LCD display to visually display the altitude (with respect to the turn on or calibration pressure) to the user. The system is powered by a battery pack containing 4 AA batteries that run the entire system.

The basic operation of the device, from initial power-up to delivery of the compensated pressure value is shown in Figure 4. The diagram relates strictly to the functions the barometric sensor can perform; the remaining operations are to be performed by the microprocessor and the corresponding system programming code is shown in Figure 5.

The barometric sensor takes pressure measurements and stores several of its components into 6 coefficients. Each coefficient is divided into two bytes: the 8 most significant bits form the MS byte; the 8 least significant bits form the LS byte. In total, there are 16 bytes which the microprocessor must retrieve from the sensor for every coefficient. Additionally, the sensor also computes two other parameters: pressure and temperature, which are 10 bits long. Due to this, the 8 most significant bits are stored in the MS byte, and the remaining 2 least significant bits are stored in the LS byte with left justification [5].

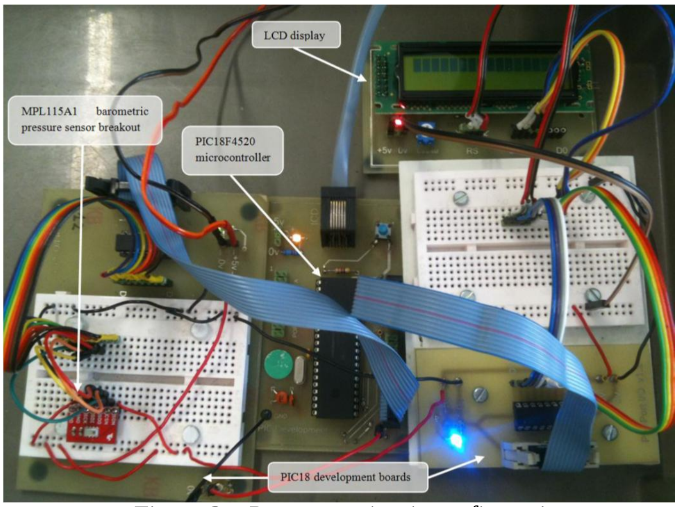

Figure 3 – Prototype circuit configuration

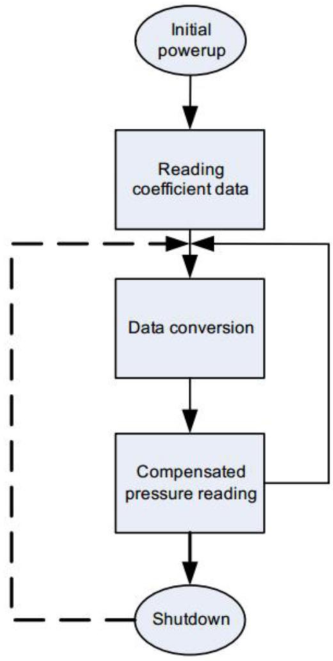

Figure 4 – General operation of the MPL115A1 sensor [5]

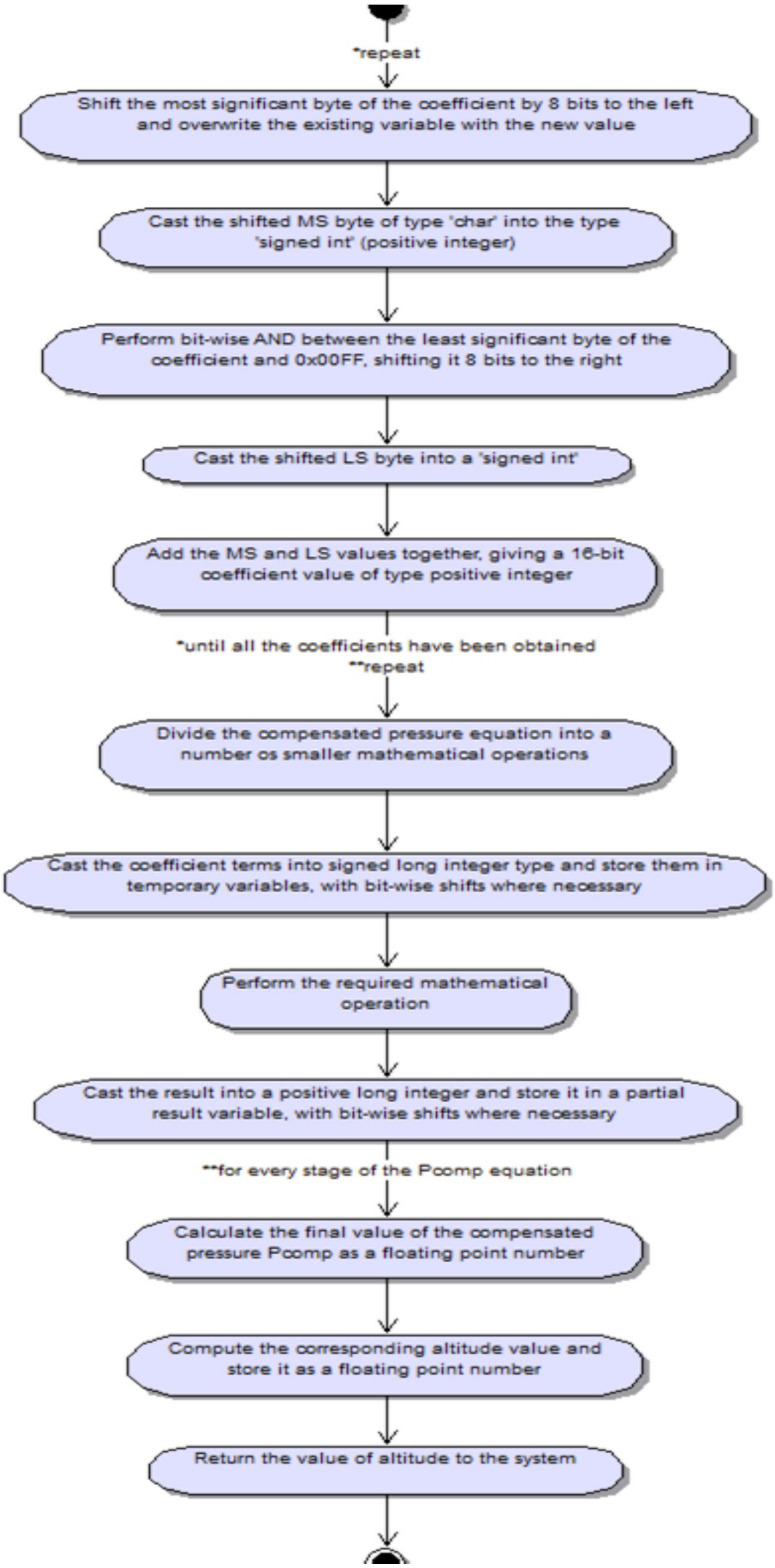

Figure 5 – Description of the PIC18F code to calculate the altitude

The value for pressure obtained thus far is in reality the normalised value of pressure. The 10-bit digital value has $2^{10} = 1024$ logical levels for pressure [0, 1023]. However, the sensor input range is 50 kPa to 115 kPa. The programming code must therefore perform the necessary mathematical operations to scale the value of pressure from its normalised value to its corresponding value within the 50-115 kPa range.
After obtaining the final value of the output compensated pressure as a floating point number (Pcomp), the altitude must be derived from Equation 1.

For commercial applications, the prototype shown in Figure 3 can be reduced to a much smaller version. A prospective PCB design / circuit schematic are shown in Figure 6. The external circuit components, such as the LCD display, the switch and sensor, are to be mounted on their respective slots. As shown, the system is reduced to a size of 50 x 77mm, which can easily be incorporated into a small sized module and transported. Minimal size also means minimal weight, meaning it could be added on as a modular component to a MAV or robot with a camera relaying the altitude displayed back to the pilot/controller. Other modules that display different sensor data could be added in the same way or used as standalone by the user.

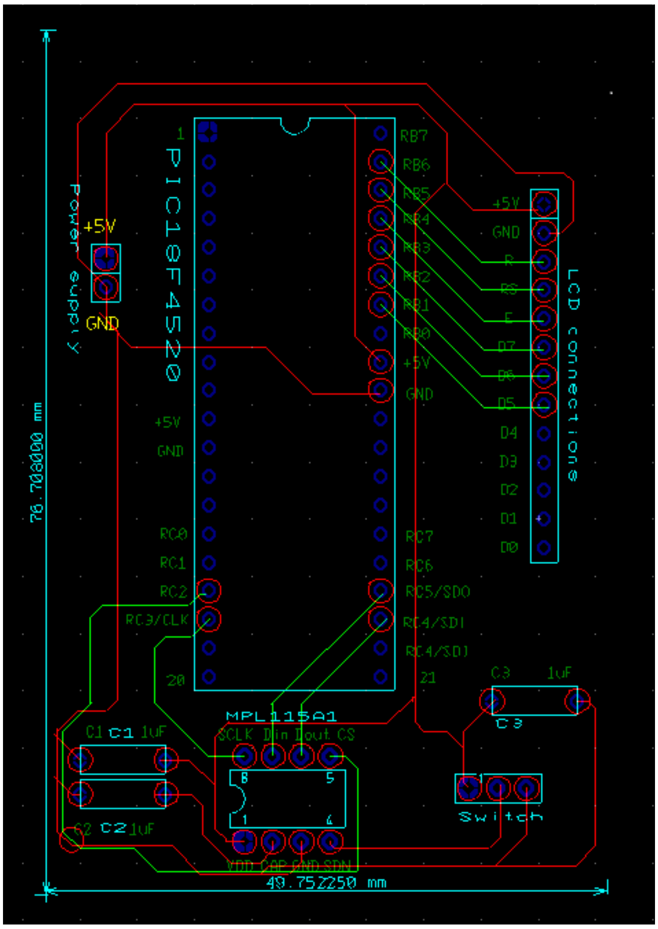

Figure 6 – The PCB design schematic

A 3-dimensional view of the board is shown in Figure 7, although it is possible to reduce the area of the PCB further, the design was created for straightforward interpretation of the connections between components and placement in space. This was to facilitate easier repair and maintenance if required.

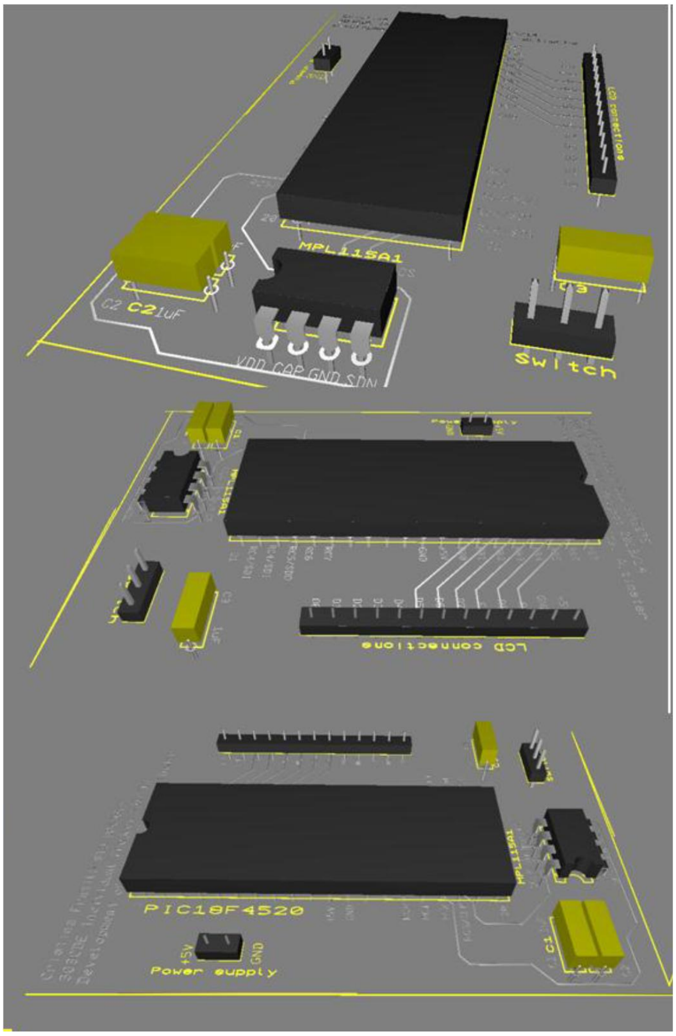

Figure 7 – The PCD design (top 3D view)

A prospective final appearance of the system for a portable device is shown in Figure 8. The module is to contain all the necessary elements, connectors and a holder for the battery. For an aerospace application (such as a light aircraft), the system would be contained within a smaller module or installed as part of a larger system due to space constraints.

III. Experimental Results

The test procedure employed was to use a suitable air-pressure sensor to compare the designed system against. The most accurate found was an app on the Samsung Galaxy S4. Measurements were taken from a building where the exact specifications/blueprints were obtained and the height known.

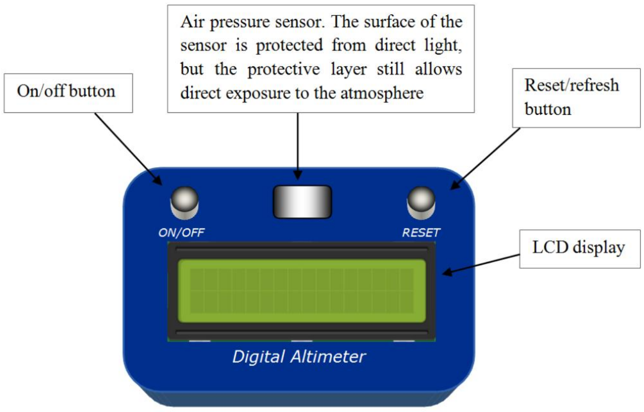

Figure 8 - Prospective design of the final product, implemented on a portable altimeter device

Figure 9 – (a) Comparison data obtained from a Samsung S4 Mobile phone; (b) Data observed from the LCD screen in the designed system

Measurements were taken from the Lower Ground floor and Roof of the Engineering and Computing Building at Coventry University. From the blueprints this was found to be 24 meters between the floors. Measurements were taken one after another in quick succession to prevent any changes in weather patterns from affecting the collected data. The tests on the mobile app were done concurrently and screenshots taken. The results are shown in Figure 9, as can be seen from parts (a) and (b), the distances match so over the limited distances the device has been tested on, it has proved to be extremely accurate.

IV. Conclusions and Future Work

The main contribution of this paper is the development of a flexible altimeter device which uses a simple barometric pressure sensor interfaced with a powerful, small size microcontroller. The system offers great improvability and a strong platform for further development.

This paper has presented a functional compact air pressure sensor that can be used to determine the height in relation to a calibration point. Future work could involve an auto-calibration feature to compensate for weather patterns on a day to day use basis (if required). Additional tests at altitude should be undertaken by installing the sensor in a light aircraft, and comparing the sensitivity at much higher altitudes against the onboard instruments.

References

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